Pollution and plant evolution

Old mine workings, badly polluted by heavy metals, are often occupied by resistant forms of a few plant species. Tolerant populations evolve rapidly and exist in a balance between gene flow from outside and selection pressure from within the toxic area. Breeding and sowing such tolerant plant strains offers the best possibility of reclaiming derelict land contaminated with lead, zinc, tin and copper

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Botanists usually work on natural vegetation and disregard man-made habitats in the belief that, since these are artificial, they are not interesting and have no scientific value. Recent work on old metal mine workings scattered all over Britain shows how wrong this is.

The piles of waste or tailings, left after the extraction of minerals, are particularly nasty environments. Although extraction procedures removed the bulk of the metal concerned, at least 1 per cent was usually left behind. In Britain the main metals that have been mined are lead, zinc, tin and copper—all extremely toxic to plant growth. But old mine workings are extreme sites also because of the very low levels of major plant nutrients, and in many cases because of the open porous nature of the soil.

It might be imagined that such extreme sites would have no vegetation. In fact, a few species do grow on them. What are these species, how do they manage to survive, and what processes have lead to them being able to colonise these curious habitats?

In Britain the main species found on soils contaminated by heavy metals are bent grass (Agrostis), fescue (Festuca), sorrel (Rumex acetosa), and plantain (Plantago lanceata). In nearly all cases the species found growing on metal-contaminated soil also occur on ordinary soils. A species which grows on toxic soils must possess some form of tolerance. Does each species have this tolerance throughout its range, or are only those populations which occur on toxic soils tolerant?

We and others have developed a simple technique for studying metal tolerance by examining the root performance of cuttings or seedlings in culture solutions with and without metal. Using this, it has been found that populations of species growing on toxic soils are able to continue rooting in conditions which are so toxic that ordinary species cannot produce roots at all. Normal pasture populations of these "mine species" show complete lack of tolerance, like other species which are never found on mine waste. Thus the reason why species are found on mine dumps is not because they possess a universal tolerance to the metals concerned, but because they are able to manifest this tolerance in appropriate populations. Tolerance is clearly an inherent, genetical characteristic. It appears to be controlled by several genes, and must have been produced as a result of normal processes of evolution.

The waste left by mining may contain any of a number of different metals, singly or in combination. Bent grass and sorrel, for instance, can be found growing on most of these different soils. Tolerance appears to be specific to individual metals: tolerance to one metal is not necessarily

Figure 1 Dereliction of a lead and zinc mine at Trelogan, Flintshire

associated with tolerance to others. But when we sample populations from waste which has more than one metal in it, we find that the plants have tolerance to all the metals involved.

How is such tolerance caused? Plants growing on mines may contain very considerable quantities of metal. But if we feed metal to tolerant and non-tolerant plants, there is little difference in the total uptake; if anything, tolerant plants take up more metal. As these different metals have very widespread effects in biological systems, tolerant plants must either render the metal innocuous or contain enzyme systems which are unaffected by the metals. When zinc-65 is added to macerates of root tissues of tolerant and non-tolerant plants, the zinc is taken up preferentially by the cell wall fraction in the tolerant plants; in non-tolerant plants it is taken up mostly by the mitochondrial fraction, and not by the cell wall. This suggests there is a complexing system which renders the metal innocuous.

Mine workings, however, pose more problems for plant growth than just high levels of metal toxicity. There is usually an acute shortage of major plant nutrients, particularly phosphorus and nitrogen. It is therefore interesting to find that mine populations of Agrostis tenuis are more tolerant of phosphorus deficiences than are normal populations. Moreover, soil moisture is likely to be extremely deficient at some periods in the year and mine populations are often dwarfer, with smaller leaves, and grow more slowly—all adaptations to moisture stress.

Most British mines have been created in the past 200 years. This suggests that tolerant populations evolve rapidly. But some may be 1000 or 2000 years old and it is perfectly possible that seeds have been carried from old to new mines with the movement of mineworkers. This means that tolerant populations could at least be as old as the oldest mines. However, many of the ore bodies must have been exposed at the surface long before there was any mining. The effect of toxicity on vegetation has long been used for prospecting for metals and is readily visible in many parts of the world at the present day. So tolerant populations need not have evolved recently at all.

But this should not be taken to mean that tolerant populations cannot evolve rapidly. In the lower Swansea Valley metal-tolerant populations have been found on the waste from smelting activity which has occurred during the past 200 years. These populations are likely to have evolved within this time. Plants growing under galvanized iron fences established in the Breckland in 1936 are tolerant to the zinc which washes off the wire. This puts the rate of evolution of metal tolerance similar to that observed by Dr H. B. D. Kettlewell for industrial melanism in the peppered moth (Biston betularia). But it looks as though it can be faster than this.

If seed of a non-tolerant population of Agrostis tenuis is sown on mine soil, the seed germinates but then dies. However, about three or four seedlings in a thousand of the non-tolerant population do continue growing, just as well as tolerant seedlings. If subsequently they are tested it is found that some possess tolerance, often equal to that of already tolerant material. Evolution of tolerance can, therefore, be almost instantaneous, although the number of individuals produced by such a screening process in the first generation may be very small.

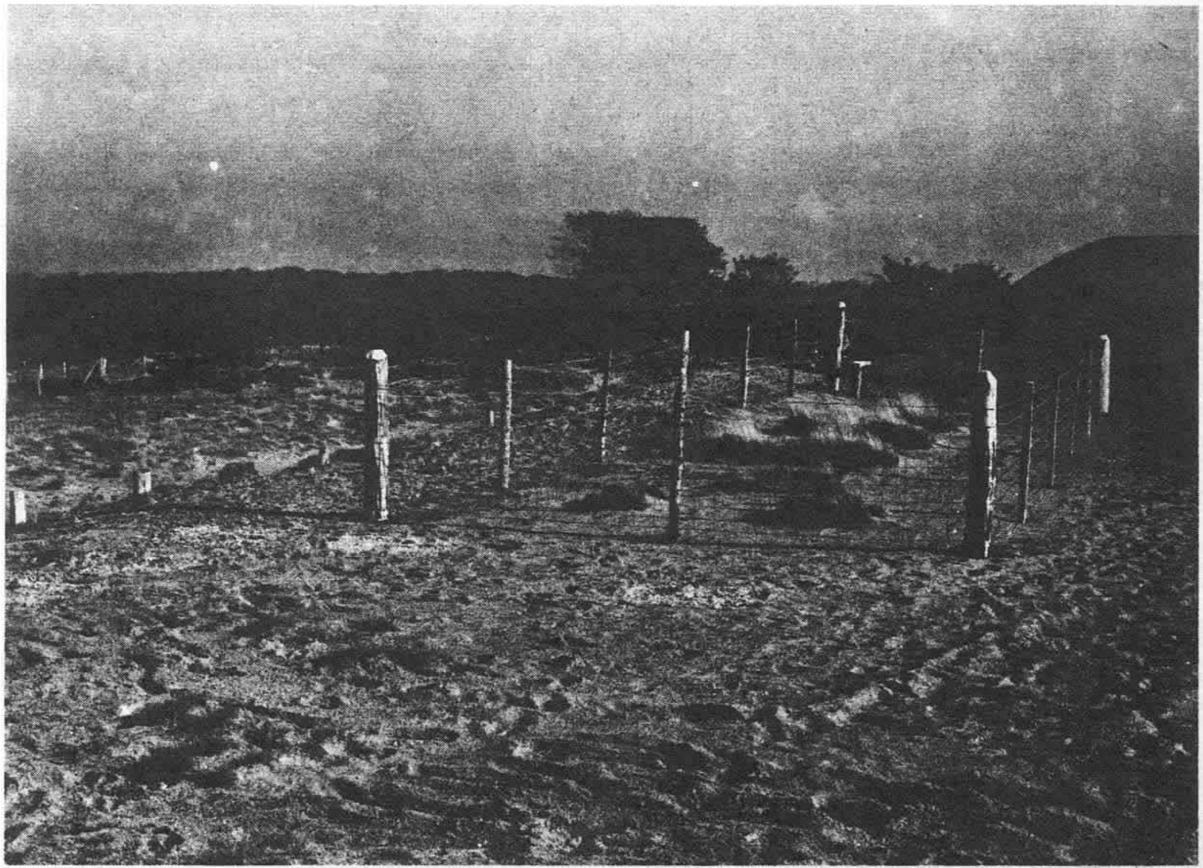

Figure 2 Tolerant plants in toxic soil, growing as well as they do in normal soil

Many of the species that have evolved tolerance are wind-pollinated and out-breeding. Does this mean that tolerant populations occur only when they are well isolated from normal populations, so that gene flow by movement of pollen does not occur? In fact, this is not so, for tolerant and non-tolerant populations sometimes occur within very few feet of one another. Tolerant populations have been found on mine dumps only 10 yards across.

The movement of pollen by either wind or insects is much less than most people imagine. Although some pollen is carried a long way, most falls within a few metres: the amount of cross pollination that takes place over seven metres in grasses is only 5 per cent. So gene flow is not very great. But it does occur, and as populations do not become muddled together, selection must be acting to prevent the effects of gene flow.

The selection on mine soils is very severe and eliminates all non-tolerant individuals immediately. But on ordinary soils the power of selection in eliminating genes acts rather differently. Although tolerant plants will survive on ordinary soils, in competitive situations they are at a disadvantage. All this adds up to the fact that the levels of selection in nature are sufficient to hold the blurring effects of gene flow in check. A model of this can be made which produces results very similar to those observed in nature (Heredity, vol 21, p407).

Recently, one population has been examined in detail, at Drws-y-Coed (Heredity, vol 23, p 99). It is a copper mine, in the middle of a "U" shaped valley which lies east and west and is subject for most of its time to á westerly wind. As a result, gene flow must be mainly in one direction. The transition from non-tolerant to tolerant populations upwind of the mine is very precise. However, in a transect taken downwind from the mine, the transition is much more gradual: some tolerance is found as much as 150 metres downwind. The tolerance of seed produced by the plants *in situ* gives an indication of gene flow (figure 1). On the upwind side of the mine, the seed is less tolerant than the adults, due to gene flow from non-tolerant populations outside the mine. Outside the mine, and downwind, the seed produced is more tolerant than the adults: this is explicable only if there is gene flow from the mine into the ordinary populations. Thus there is a tendency for the tolerant mine population to be drowned by non-tolerant genes coming in from upwind, but because selection pressure is very strong this gene flow is kept in check. On normal soils, downwind of the mine there is gene flow of tolerant genes coming out from the mine. In this case selection pressure is not so strong: the population downwind of the mine are still somewhat tolerant.

All this indicates that mine workings have a great deal to tell us about evolution. We can see not only that evolution has occurred, and that meticulously-adapted populations now exist on mines, but that this can occur very rapidly. Furthermore, such populations are not static once they have been formed; their composition is the result of a balance between selection and gene flow.

The wastes of a mine working are, of course, unattractive and can be a considerable source of pollution. Finely ground tailings can blow or wash into surrounding areas, and, because they are toxic and low in nutrients, can ruin farmland. Although individual heaps are small, over the British Isles as

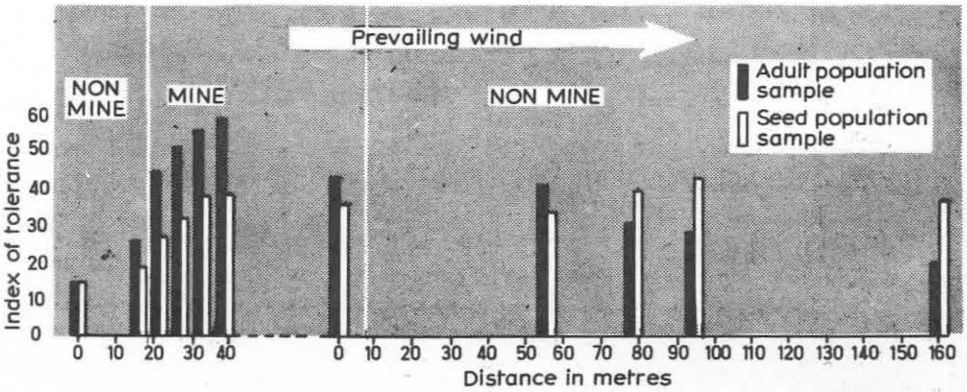

Figure 3 Population differences and gene flow on a small copper mine Drws-y-Coed in Caernarvonshire. The tolerance of seed populations shows that gene flow is occurring, so that the potential of differentiation is blurred. But the tolerance of adult populations shows that the actual differentiation is very clear cut due to the action of natural selection, although downwind the tolerance does spread into the pasture (non-mine) because of excessive gene flow

a whole they total several thousand acres. They are a heritage of our industrial past that we can do without, and attempts are now being made to establish vegetation on them. Up to now the only practice has been to cover them up with a layer of normal soil, but this is highly expensive and usually impractical.

There is no way in which one can remove the toxic metals, and waiting for them to leach out would involve tens of thousands of years; smelter waste actually becomes more toxic as the material breaks down. There are no obvious additives that can be used to overcome the effects of the metals. However, tolerant plants are completely unaffected by the toxicity and if these are sown the problem is immediately overcome.

The other major problem, lack of major plant nutrients, can easily be defeated by using fertilizer. Moisture shortage does not seem important. Although the surface of the waste may become excessively dry, there is usually adequate moisture a few centimetres down. If plants can develop adequate roots, they will not suffer from drought.

The technique of using tolerant populations and fertilizer is being tested in Swansea and at Liverpool. The results so far are very encouraging (Nature, vol 227, p 376). The growth of tolerant populations of various species, particularly Agrostis and Festuca, is so satisfactory that good swards can be formed in less than a year. If non-tolerant populations are used, this is far from true: they may hang on, half alive, for six or nine months, but at the end of a year they are dead. The best results are obtained if a slow-acting fertilizer is used, giving a continuous long term release of nutrients.

Old mine workings may not have beauty in the romantic sense, but their intellectual beauty is considerable. They are near at hand, distinctive, definable, often of a known age, and ecologically simple. Many factors, such as competition, biotic effects, and pre-history, which are complicated in natural plant communities, do not apply on mine waste. So it is that these areas, once disregarded, have suddenly become scientifically very rewarding.